Assumptions

1. Percent of CPE antennas with same polarization as the satellite 50%
2. Percent of CPEs with clear path to the satellite 50%
3. Percent of CPEs simultaneously active 50%

Maximum EIRP in clear air is:

EIRP(Max) = Tx Power + Antenna Gain - 10 log(BW)
= -17dBW + 34dB - 10 log(2.5 MHz)
= 13dBW/MHz

Since CPEs are uniformly distributed and power control is used to normalize the received power at the hub, the average EIRP is:

EIRP(Ave) = EIRP - 3dB
= 13dBW/MHz - 3dB
= 10dBW/MHz

The average number of subscribers on the same frequency is:

Ave Subscriber/channel = Max Number of Subscribers/Channels
= 4608/48
= 96

The average number of CPEs operating within a 2.5 degree beamwidth and on the same frequency is:

Ave CPEs (2.5 degrees) = 2.5/360
= 0.67

The average area per subscriber terminal operating within a 2.5 degree beamwidth is:

Ave Area = 75 km^2 /0.67 where 75 km^2 is the area of a 5 km cell
= 112 km^2

Peak power spectral area density is:

PSD(peak) = EIRP (Ave) - 10 log(Ave area)
= 10 dBW/MHz - 10 log(112)
= -10.5 dBW/MHz-km^2

Power spectral density average with a 4% duty factor is:

PSD(Ave) = PSD(peak) + 10 log(0.04)
= -10.5 dBW/MHz-km^2 + 10 log(0.04)
= -24.5 dBW/MHz-km^2

Area density of 250 hubs in the 200km X 400km area is:

Area density (250 Hubs) = [(200km X 400km)/75]/250
= 4.27

Thus, the power spectral density over the 200km X 400km area is:

PSD(area) = PSD (Ave) + 10 log(4.27)
= -24.5 dBW/MHz-km ^{2} + 10 log(4.27)
= -30.8 dBW/MHz-km ^{2}

Accounting for the number of CPEs with the same polarization, (50%), clear path to the satellite, (50%) and those that are simultaneously active, (50%) the PSD for the area becomes

PSD(area %) = -30.8dBW/MHz-km ^{2} -9dB
= -39.8dBW/MHz-km ^{2}

This represents the peak of beam of the CPE antennas pointed at an angle of 5 degrees or less above the horizon.

Adjusting the PSD for the increased area:

Area increase = 10 log(10)
= 10 dB

results in a PSD of

PSD = PSD(area %) + Area Increase
= -39.8 dBW/MHz-km ^{2} + 10 dB
= -29.8 dBW/MHz-km ^{2}

and accounting for the 6.25 MHz receiver bandwidth and 2.5 MHz CPE transmit bandwidth the PSD is

PSD = PSD + 3DB
= -29.8 +3
= -26.8 dBW/MHz-km ^{2}

This is better than the required -26 dBW/MHz-km ^{2} required.

Not accounted for is the reduction in power for those CPEs which are close in to the Hub and further have their power reduced by another 11 to 17 dB. Thus, the above analysis demonstrates that with reduced power for clear air and power control the LMDS CPEs and the Iridium satellite receivers are able to co-share the 29.1 to 29.25 GHz band.

APPENDIX B

APPENDIX B LMDS BOUNDARY COORDINATION

Analysis of Mutual Interference of LMDS Hubs Along BTA Boundaries

This analysis evaluates potential interference between two LMDS services along BTA boundaries, and the effectiveness of various approaches to mitigate such interference. The approach used here is to first evaluate potential interference to subscriber terminals located along a BTA boundary as a result of hubs located in the adjacent BTA when no mitigation techniques are used. The impact of such interference is assessed. Then the use of polarization to reduce interference is shown to reduce interference for only a small number of potential subscribers. This is then contrasted to the benefits of polarization to increase spectrum use efficiency. Other mitigation approaches are also suggested.

LMDS System Parameters

1. Cell Radius	5 km
2. Cell-to-Cell Spacing	5 km
3. Subscriber Antenna Beamwidth	3 degrees
4. Maximum EIRP radiated toward BTA boundary:	8 dBW/MHz
5. Minimum C/I allowable at CPE:	14 dB
6. Subscriber distribution around hubs:	Uniform

Assumptions

1. Maximum Subscriber Density in BTA:	250/sq km
2. Average BTA Size (based on area of U.S. of 9.384 million square kilometers and 462 BTAs)	20,300 sq km
3. Subscriber Density Along BTA Boundary:	20/sq km
4. Number of hubs within range of any Subscriber Terminal: 4	
5. Worst-case sub-to-desired hub distance:	5 km
6. Hubs on 5 km concentric circles and 5 km spacing around circumference around subscriber	

7. Probability of any Primary Subscriber-Hub path being blocked: 0.5
8. Probability of any Secondary Sub-Hub path not being blocked: 0.25
9. Probability of any Tertiary Sub-Hub path not being blocked: 0.125
10. All hubs transmit at same power level:
11. All hubs transmit omni-directionally
12. All hubs transmit with the same polarization.
13. All hubs within 5 km of BTA boundary transmit away from BTA boundary.

Calculations

First determine the extent of area subject to interference across BTA boundaries. The probability of interference along a BTA boundary is calculated for the configuration illustrated in Figure B1, assuming all hubs transmit at the same EIRP. First evaluate the C/I as a function of the ratio between the Subscriber-Desired Hub range to Subscriber-Interferer range. This is simply:

$$C/I = 20 \log R_I / R_{hub}$$

To meet the minimum 14 dB C/I ratio, the ratio R_I / R_{hub} must be equal to or greater than 5. A plot of this equation is shown in Figure B2 as a function of the subscriber-to-desired hub distance for a hub-to-hub spacing of 5 km. Notice that for subscriber-to-desired-hub distances of 1 km or less, the C/I ratio is greater than the minimum required based on free-space loss only. (If hubs do not all transmit at the same EIRP, this ratio changes accordingly.) Thus all hubs greater than 20 km from a BTA boundary are not an interference problem, provided all hubs transmit at the same power level.. For a 100 km X 200 km area, the percentage of area which is greater than 20 km from the BTA border is:

$$(100 - 40)(200-40)/20{,}000 = 0.48 \text{ or } 48\%.$$

The remaining 52% of the hubs are <u>potentially</u> capable of causing interference across BTA borders. In addition, subscriber terminals located less than 20 km from BTA boundaries are subject to <u>potential</u> interference from neighboring BTA hubs. The issue of interference mitigation must be addressed because of the high percentage of area which is subject to potential interference along BTA boundaries. This does not, however, imply that all subscribers within an area of potential interference will suffer interference, but that there is a small percentage of possible subscribers that will suffer interference across BTA boundaries. The question of how extensive the interference problem can be is addressed first. Then various mitigation effects are evaluated.

Referring to Figure B1, the arc length "illuminated " along the first tier of interfering nodes is calculated as:

$$s = (3/360)*2*pi*R = 0.0166*pi*5 \text{ km} = 0.262 \text{ km}$$

The hub spacing, S, around the ring is 5 km. Hence the probability of a subscriber antenna beam encompassing an undesired interfering hub along the first ring is:

$$P_{hi} = s/S = .262/5 = 0.052$$

The probability of encompassing a hub from the second tier is 2*0.052 = 0.104; and for the third tier, it is 3*0.052 = 0.156.

The probability of the path not being blocked between the subscriber and the first tier interfering node is assumed to be 0.5; for the second tier, 0.25; and for the third tier, 0.125. These probabilities are based on the assumption that the probability of blockage is 0.5 for each 5 km of distance traversed (which was obtained from propagation measurements).

The probability of any one subscriber-to-desired-hub path being blocked is 0.5. With the assumption that a subscriber has four possible paths to a node, and given that one path is "blocked" by interference, then three possible paths remain; the probability that the path is blocked on all three is:

$$P_{blk3} = (0.5)^3 = 0.125$$

The probability of unavoidable interference to any given subscriber within 5 km of the BTA boundary from an interfering first-tier hub in the adjoining BTA closest to the BTA boundary is:

$$p_1 = p_{hi} * p_{bk} * P_{blk3} = 0.052*0.5*0.125 = 0.00325$$

For interference from a second-tier hub, the probability of interference is 0.00325 and from a third- tier hub, it is 0.0023. Then the total probability that any given subscriber within 5 km of the BTA boundary will be interfered with from a node in the adjoining BTA is simply the sum:

$$P_{tot} = 0.00325 + 0.00325 + 0.0023 = 0.0088$$

Next consider the interference caused to subscribers located 10 km from the BTA boundary. The geometry is the same, but now hubs from the third tier no longer cause interference. Thus the total probability of interference is now:

$$P_{tot} = 0.00325 + 0.00325 = 0.0065$$

and for subscribers located 15 km from the BTA boundary, it is 0.00325.

Subscribers located at least 20 km from the BTA boundary experience no interference from adjacent hubs due to free space loss alone. The total number of subscribers which are subject to interference is a function of subscriber density along the boundary and the area subject to the interference. If a BTA geometry of 100 X 200 km is assumed and the 200 km boundary is taken, then the area included within 5 km of the border is simply 5*200 = 1000 km^2. The area around the entire perimeter is simply 2*5*200 + 2*5*90 = 2900 km^2.

Since the subscriber density along this boundary is 20 per square kilometer, the expected number of affected subscribers along the perimeter is:

0.0088*20*2900 = 510

For the subscribers between 5 and 10 km of the BTA boundary, the area is 2700 km^2, the subscriber density is assumed to be 40 subscribers per km^2 and the probability of interference is 0.0065. Thus the number of subscribers affected is:

0.0065*40*2700 = 702

Similarly, the number of affected subscribers within the 10-15 km zone along a BTA boundary is:

0.00325*80*2500 = 650

Therefore the total number of expected lost subscribers due to interference form hubs in the adjacent BTAs is 510 + 702 + 650 = 1862. (As a worst-case, assume that the subscriber density is the average of 250 subs/ km^2; then the number of affected subs is 13,000.) The total number of potential subscribers in a BTA, based on the assumed values, is:

250*20,300/2 = 2.5 million subs

The expected percentage of lost subscribers is:

1862/2.5 million = 0.00074 = 0.074%

Even for the worst case of 250 subs/ km^2, the percentage is only 0.5%. Therefore for the expected case, i.e., where the subscriber density is minimal along BTA boundaries, the number of subscribers lost due to interference from hubs in the adjacent BTAs is less than 0.08%. The key to this low rate is that the EIRP from hubs on either side of the BTA boundary must be the same. This implies that the EIRP from hubs must be either regulated or coordinated. Since coordination between four or more service providers may be required, it seems more appropriate to coordinate the EIRP for hubs. The following EIRP limits are proposed for clear-air conditions:

Hubs within any BTA boundary transmit power toward the BTA boundary according to the following schedule:

Distance from BTA Border	Maximum Hub EIRP Toward the BTA Boundary
d < 5 km	-40 dBW/MHz
5 km d < 10 km	-10 dBW/MHz
10 km d < 15 km	-6 dBW/MHz
15 km d < 20 km	-4 dBW/MHz
20 km d	-2 dBW/MHz

The effective EIRP is allowed to increase to compensate for rain or other atmospheric loss provided that the power transmitted across a BTA boundary under such conditions is no greater than that for clear air conditions.

The above calculations assumed that no other mitigation methods were implemented, and that the LMDS system served maximum population densities. The lost coverage calculations were based solely on losses due to interference from adjacent BTA hubs. With the same assumptions used for the previous calculations (i.e., the probability of any one subscriber-to-hub path being blocked is 0.5), then the probability of lost coverage due to path blockage is $(0.5)^4 = 0.0625$ or 6.3%. Even under "ideal" conditions, the coverage is expected to be no greater than 99%. The expected loss due to interference from adjacent BTA hubs is only 0.08%. This is insignificant compared to the 1% to 6% loss expected from other factors.

Next consider other mitigation factors such as polarization. If polarization were 100% effective, the coverage improvement expected would be 0.08%. However using orthogonal polarization to mitigate interference between BTAs is not perfect. Consider three BTAs which adjoin. Since only two different polarizations are available, one BTA will be forced to have the same polarization as one of the other BTAs. Also even in a "perfect" checkerboard pattern of BTAs, polarization will be the same in the corners of adjacent BTAs. Hence polarization cannot be used to provide 100% effective elimination of interference across BTAs. Since polarization can be used within a cell to reduce interference due to: (1) Amplitude ripple from adjacent antenna sectors; (2) Transmit/Receive isolation and (3) Cell-to-cell interference, the use of polarization to reduce interference between BTAs is not an effective trade. Polarization is better used to reduce interference within BTAs.

Conclusions

The use of mitigation techniques which are totally effective in reducing interference from hubs located in adjacent BTA will result in very small coverage improvement (only 0.08%). The use of orthogonal polarization within a cell to reduce interference is more effective than using it to reduce interference across BTAs. The most effective means of reducing interference across BTAs is to coordinate the EIRP from hubs, particularly those within 20 km of the BTA boundary since polarization is not a major mitigation factor. The following schedule is suggested for clear-air conditions as an example.

Distance from BTA Border	Maximum Hub EIRP Toward BTA Border
d < 5 km	-40 dBW/MHz
5 km d < 10 km	-10 dBW/MHz
10 km d < 15 km	-6 dBW/MHz
15 km d < 20 km	-4 dBW/MHz
20 km d	-2 dBW/MHz

The effective EIRP must be allowed to increase to compensate for rain or other atmospheric loss. Also, polarization should be applied only if shown to be necessary for a particular interference geometry.

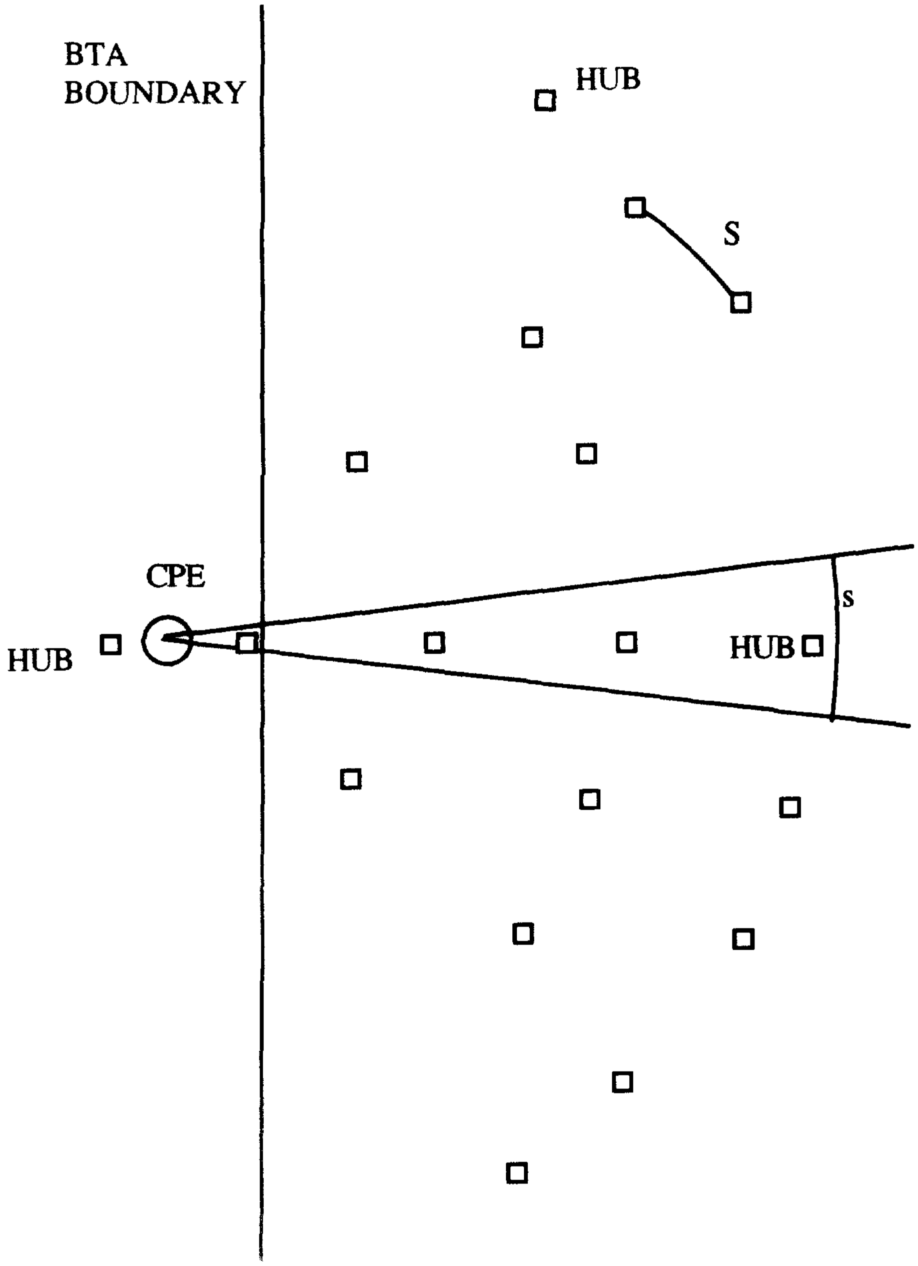

Figure B1. Hub and Subscriber Terminal Geometry for Analysis of Interference Along BTA Boundaries

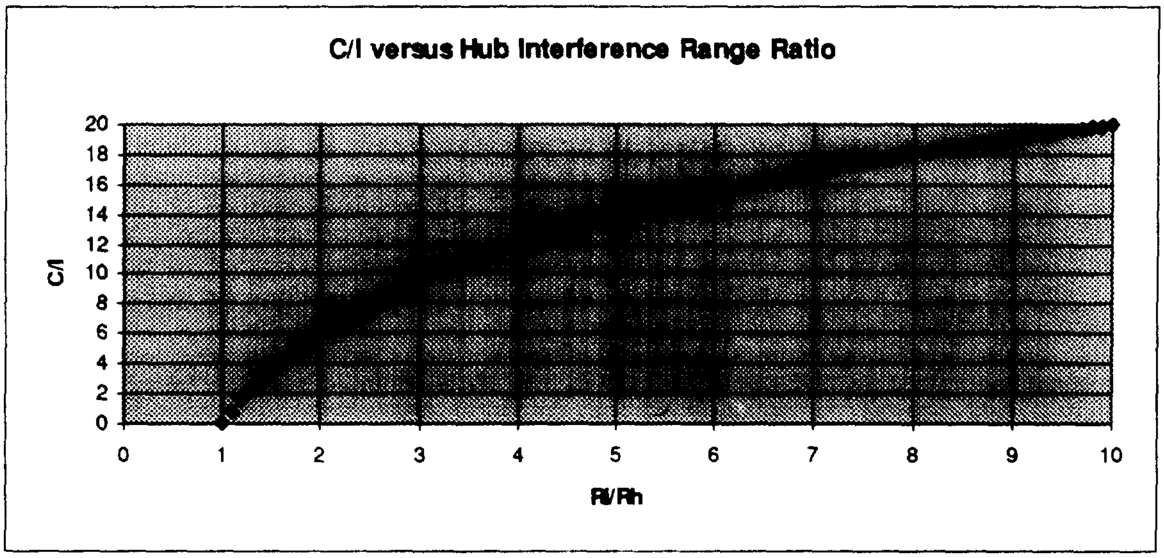

Figure B2. Interference (C/I) as a Function of the Ratio of Range-to-Interference and Range-to-Hub.